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SPACE SHUTTLE
Solid Rocket Motors
Thiokol Corporation

Systems Tunnel Linear Shaped Charge Lightning Strike Final Test Report

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Thiokol CORPORATION
SPACE OPERATIONS

P.O. Box 707, Brigham City, UT 84302-0707 (801) 863-3511

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Systems Tunnel Linear Shaped Charge Lightning Strike Final Test Report

Prepared by:

Mart Cook

Test Planning and Reporting

Approved by:

8-3-89

Requirements and Certification Manager

8-6-89

Project Engineer

Joe Godfrey

Program Manager

Fred Duersch Jr 3 Aug 89

Reliability

PC Tydeck 8-7-89

Data Management

ECS# SS1601

ABSTRACT

Simulated lightning strike testing of the systems tunnel linear shaped charge (LSC) was performed at the Thiokol Lightning Test Complex in Wendover, Utah, on 23 Jun 1989. The test article consisted of a 160-in. section of the LSC enclosed within a section of the systems tunnel. The systems tunnel was bonded to a section of a solid rocket motor case. All test article components were full scale.

The systems tunnel cover of the test article was subjected to three discharges (each discharge was over a different grounding strap) from the high-current generator. The LSC did not detonate. All three grounding straps debonded and violently struck the LSC through the openings in the systems tunnel floor plates. The LSC copper surface was discolored around the areas of grounding strap impact, and arcing occurred at the LSC clamps and LSC ends.

This test verified that the present flight configuration of the redesigned solid rocket motor systems tunnel, when subjected to simulated lightning strikes with peak current levels within 71 percent of the worst-case lightning strike condition of NSTS-07636, is adequate to prevent LSC ignition. It is therefore recommended that the design remain unchanged.

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ACRONYMS

DM	development motor
EPDM	ethylene-propylene-diene monomer
kA	kiloamp
kV	kilovolt
LSC	linear shaped charge
RSRM	redesigned solid rocket motor
sec	second
SRM	solid rocket motor
TPS	thermal protection system
USBI	United Space Boosters, Inc.

1
INTRODUCTION

This report documents the procedures, performance, and results obtained from the systems tunnel linear shaped charge (LSC) lightning strike test. The purpose of the test was to evaluate what effects simulated lightning strikes have on the LSC. The primary focus of the test concerned the systems tunnel-to-case grounding straps, which could separate at the strap/case interface during a lightning strike and then impact the LSC. This test was performed under a contract from United Space Boosters, Inc. (USBI). The LSC is a USBI component, and a representative of USBI was present at the test facility during testing. Testing complied with JSC 20007, NASA Lightning Protection Verification Document, and NSTS 07636 Rev D, NASA Lightning Protection Criteria Document.

The systems tunnel LSC is part of the redesigned solid rocket motor (RSRM) range destruct system and is located within the systems tunnel on the upper three segments of the RSRM. The systems tunnel floor plates are grounded with straps to the case wall approximately every 5 ft to provide a path for electrostatic and lightning current from the tunnel to the case. Each grounding strap is bolted to the floor plate and bonded to a grit-blasted surface on the case wall with STW4-2874 electrically conductive adhesive (Eccobond solder 56C). Grounding straps are bonded to the case surface through openings in the floor plates (Figures 1 and 2).

Testing was performed in accordance with WTP-0195, Systems Tunnel Linear Shaped Charge Lightning Strike Test Plan. Testing was performed on 23 Jun 1989, at the Thiokol Lightning Test Complex in Wendover, Utah. WTP-0195 was based on the following USBI test plans: SYS-10-PLAN-001, SRB Systems Tunnel CO 191 Lightning Coupling Test Plan, and 10-PRC-0581, Linear Shaped Charge Assembly Procedure--Lightning Test. This test was part of an ongoing lightning strike test program to evaluate the complete RSRM and Space Transportation System under the effects of lightning strikes.

1.1 TEST ARTICLE DESCRIPTION

The test article consisted of a 160-in. section of the LSC enclosed within a section of the systems tunnel (Figures 3 and 4). The systems tunnel was bonded to a section of a solid rocket motor (SRM) case (cut from the Development Motor 8 (DM-8) aft segment), and the tunnel included a cover and complete thermal protection system (TPS) closeout. Test article assembly was flight configuration except that the systems tunnel floor plates were installed directly over the factory joint of the case section; no splice plate was used. The ends of the tunnel were enclosed to

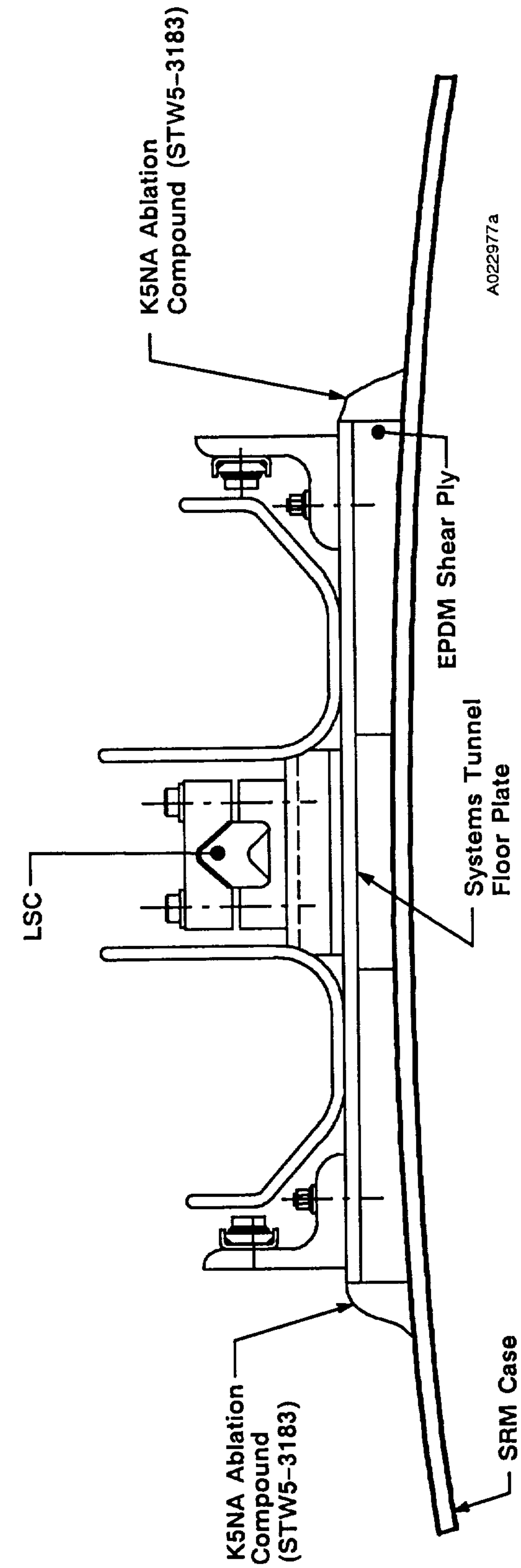


Figure 1. Cross Section of Systems Tunnel LSC Test Article (systems tunnel covers not installed)

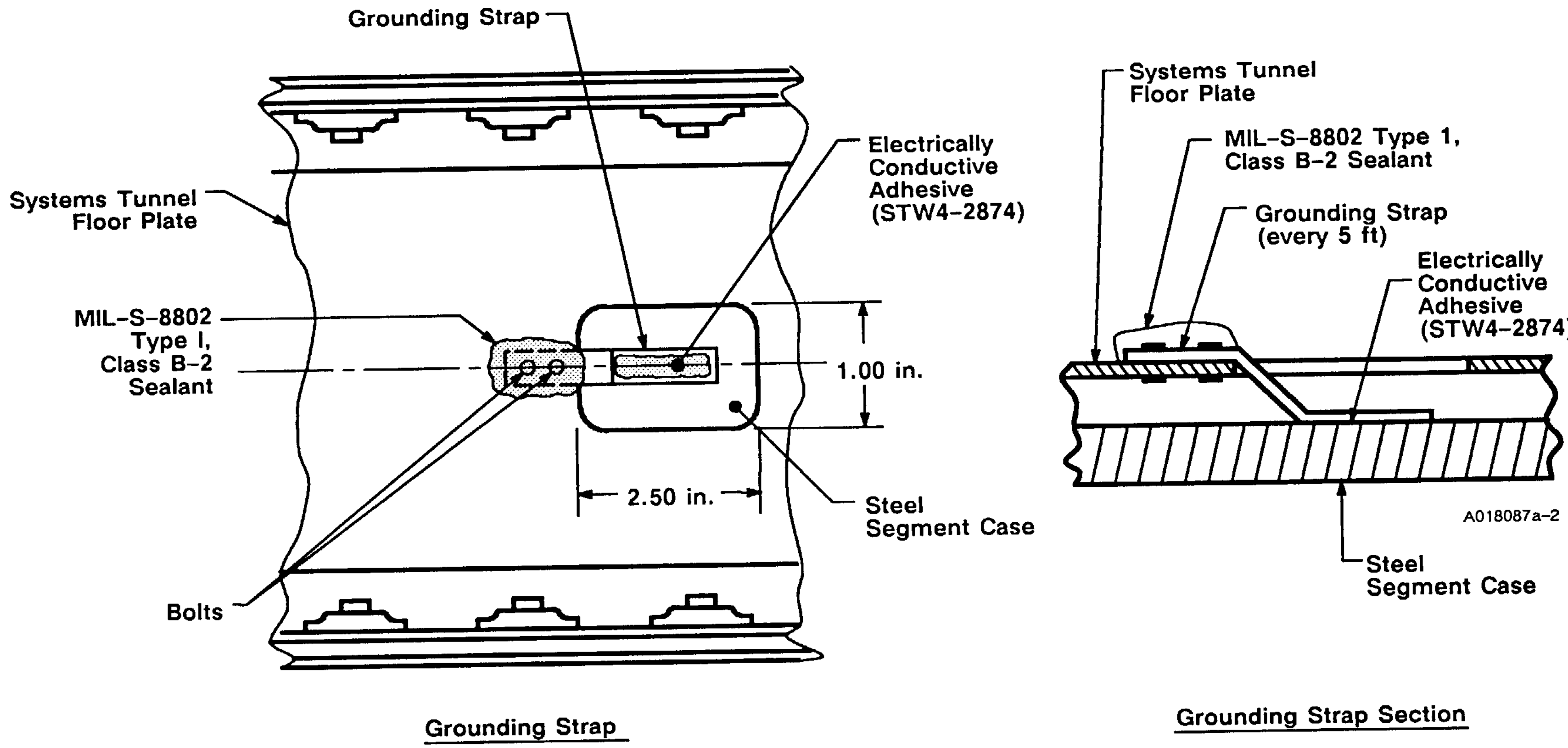


Figure 2. Systems Tunnel Floor Plate Assembly—Grounding Straps

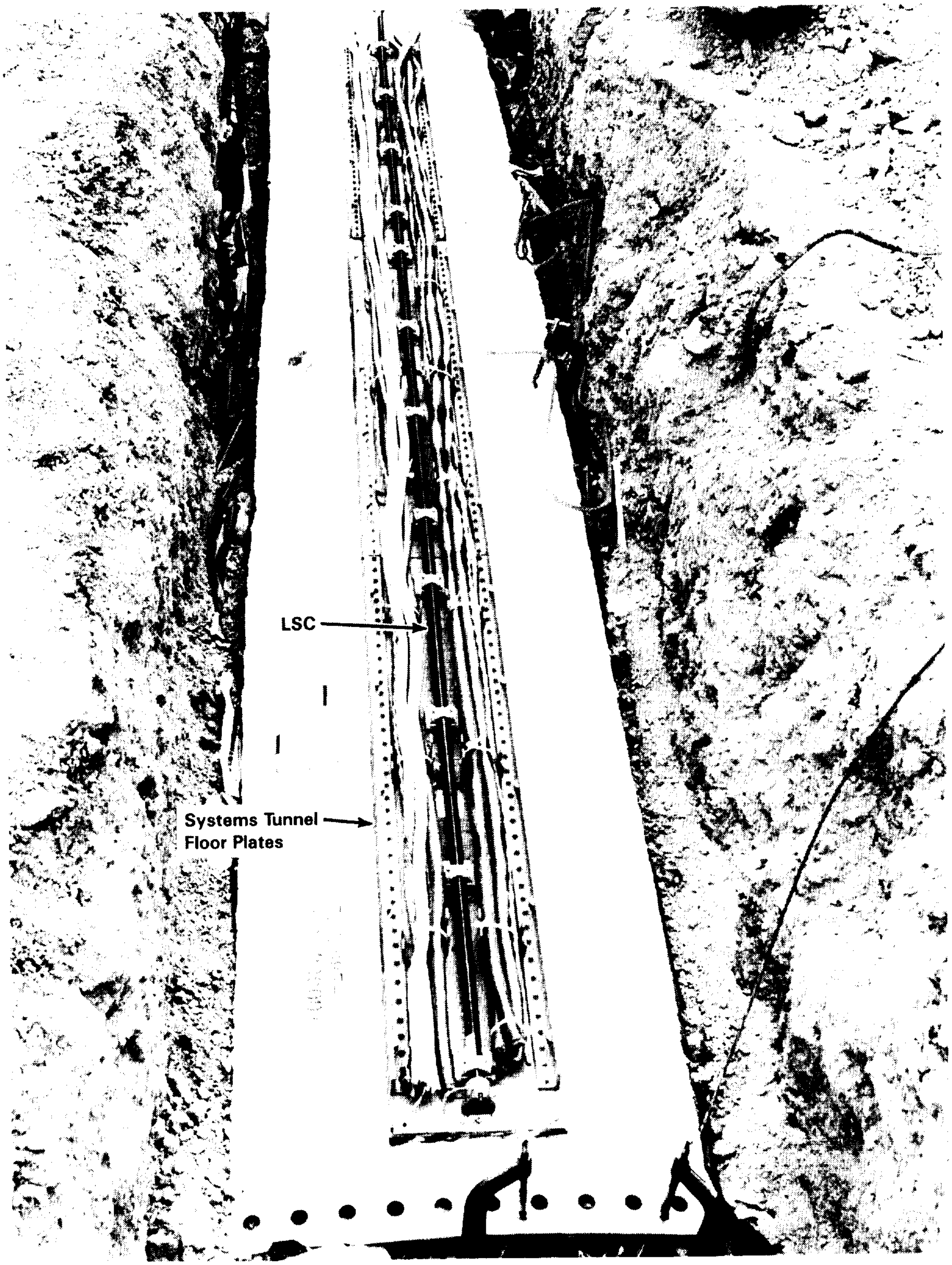


Figure 3. Systems Tunnel LSC Lightning Strike Test—Test Article Assembly (prior to systems tunnel cover installation)

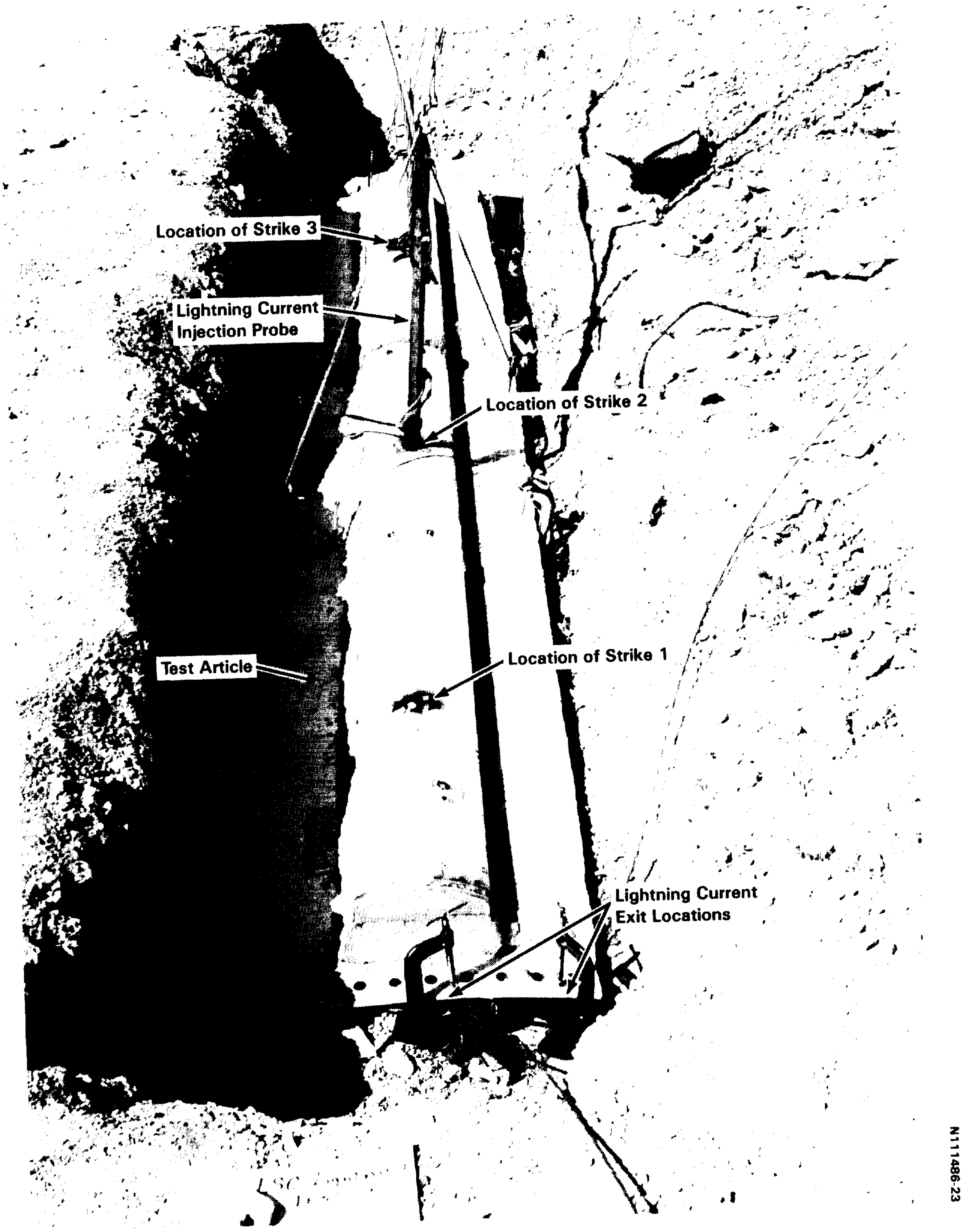


Figure 4. Systems Tunnel LSC Lightning Strike Test—Test Setup

simulate a flight condition pressure vessel. Three systems tunnel-to-case grounding straps were included in the assembly. All components of the test article were full scale. The test article was assembled per Dwg 7U76985.

2

OBJECTIVE

The test objective was to evaluate the effects that debonded (due to a lightning strike) systems tunnel-to-case grounding straps have on the LSC.

3

EXECUTIVE SUMMARY

3.1 SUMMARY

This section contains an executive summary of the key results from test data evaluation and post-test inspection. Additional information can be found in Section 6 (Results and Discussion).

The systems tunnel cover of the test article was subjected to three discharges (each discharge was over a different grounding strap) from the high-current generator. The systems tunnel and cover remained undamaged after each strike, although a section (approximately 3 in. in diameter) of TPS was blown off at each injection location. The LSC did not detonate.

After the lightning testing, the systems tunnel cover was removed for LSC visual inspection. All three grounding straps debonded and violently struck the LSC through the openings in the systems tunnel floor plates. It is assumed that the grounding strap debonding occurred only when the straps were subjected to a lightning strike from directly above. Separation of each grounding strap occurred primarily at the bondline between the strap and the adhesive.

Slight discolorations of the LSC copper surface were detected around each grounding strap impact location. These discolorations were due to the heat produced during debonding. Inspection also revealed that arcing occurred on the LSC around the areas of the saddle block clamps and at each end, indicating that current flowed on the surface of the LSC.

Removal of the systems tunnel floor plates from the case section showed that arcing occurred between these components in the vicinity of the grounding strap for the first discharge. This indicates that the injected current for this strike continued to flow through this area until the end of the pulse. Steel case surface hardening caused by the arc was significant enough to damage a case beyond repair. A small amount of arcing also occurred in the vicinity of the grounding straps for the second and third discharges. However, the raised portion of the case at the factory joint was located between these two strike locations, and a large amount of arcing between the case and the systems tunnel floor plates occurred in this area.

3.2 CONCLUSIONS

The systems tunnel was subjected (directly above the systems tunnel-to-case grounding straps) to simulated lightning strikes with peak current levels within 71 percent of the worst-case lightning strike condition of NSTS-07636. These strikes resulted in debonding of the grounding straps but caused no damage to the LSC. It is therefore concluded that the present flight configuration of the systems tunnel and LSC is adequate.

3.3 RECOMMENDATIONS

This test verified that the present flight configuration of the RSRM systems tunnel, when subjected to simulated lightning strikes with peak current levels within 71 percent of the worst-case lightning strike condition of NSTS-07636, is adequate to prevent LSC ignition. It is therefore recommended that the design remain unchanged.

Because of the localized hardening of the steel case at the grounding strap area from the first discharge, it is recommended that steel case degradation due to lightning strikes be further investigated. This investigation could determine how different levels of lightning strike discharges cause case damage on preflight and flight RSRMs. Further investigation of the LSC test article to determine the depth of hardening to the steel case and to determine the extent of diffusion of aluminum into the steel matrix is also recommended.

4

INSTRUMENTATION

Instrumentation used during this test is listed in TWR-18364, Lightning Tests Instrumentation Report.

5

PHOTOGRAPHY

Still color photographs were taken of the test article, test setup, and post-test inspection. Copies of the photographs taken (Series 111486, 111897, and 111963) are available from the Thiokol Photographic Services Department.

6

RESULTS AND DISCUSSION

6.1 ASSEMBLY

The full-scale systems tunnel floor plates and grounding straps were installed on the DM-8 aft segment case section at the Thiokol M-86 Reinforced Plastics Lab. The test article assembly differed from flight configuration in that no systems tunnel splice plate was used over the factory joint of the case section. Instead, three systems tunnel floor plate sections were installed end to end, and the thickness of the ethylene-propylene-diene monomer (EPDM) shear ply was reduced over the factory joint. The reduced thickness of the shear ply ensured a flat bonding surface between the ply and the floor plate.

The test article was then sent to the Thiokol Lightning Test Complex in Wendover, Utah, where the LSC, systems tunnel cover, and TPS were installed. The systems tunnel ends were also covered. The test article was assembled per Dwg 7U76985 and placed in a 3-ft-deep trench for lightning strike testing.

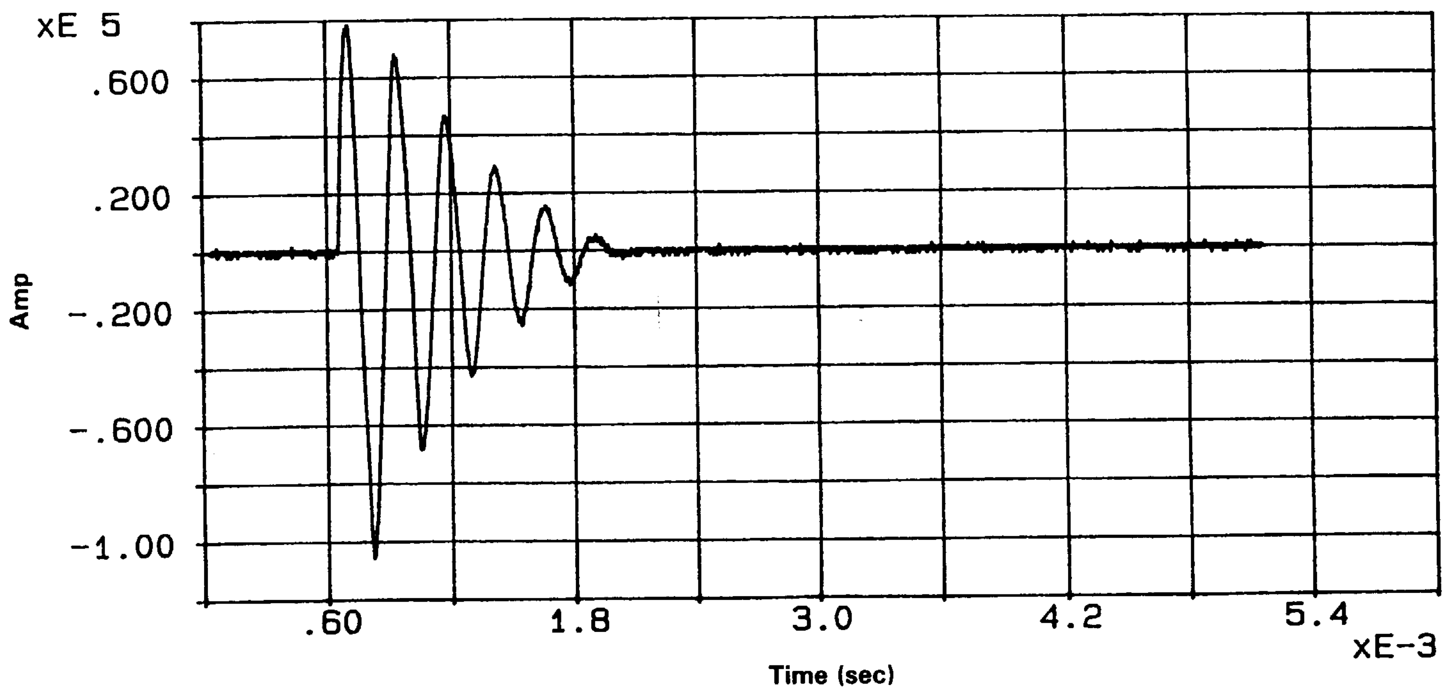
6.2 TEST

The systems tunnel cover was subjected to three discharges (each discharge was over a different grounding strap) from the high-current generator (Figures 5 through 7):

Test No.	Maximum Current	Action Integral
1	105,000 amp	1.764×10^6 amp^2 sec
2	143,600 amp	3.758×10^6 amp^2 sec
3	143,600 amp	3.685×10^6 amp^2 sec

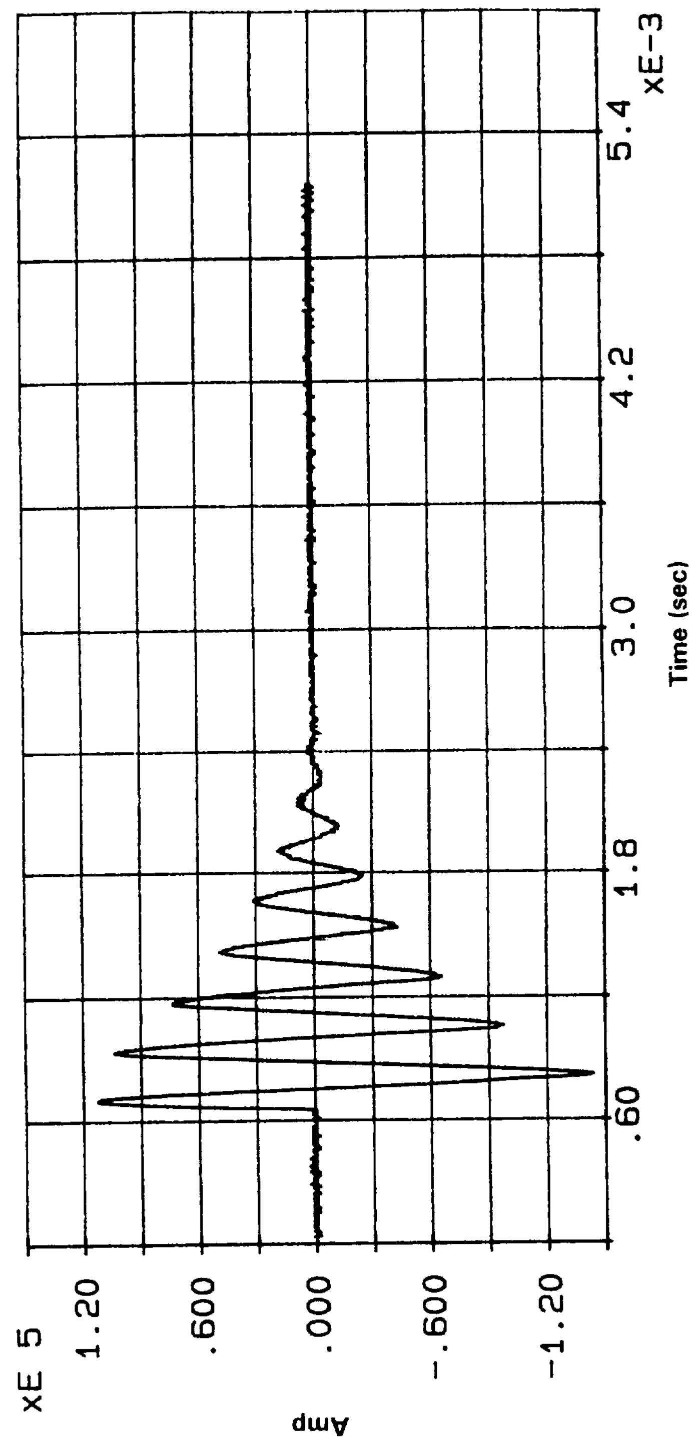
Current from each strike was grounded through cables attached to the steel case (Figure 4). The systems tunnel and cover remained undamaged after each strike, although a section (approximately 3 in. in diameter) of TPS was blown off at each injection location. The LSC did not detonate.

The minimum current injected (105,000 amp for the first test) was the lowest reliable injected current that could cause an unbond. This level is 52.8 percent of the 200 kA worst-case current called out by NASA's Lightning Protection Criteria Document (NSTS-07636). The action integral of the first test was 88.2 percent of the implied maximum of 2×10^6 amp^2 sec in NSTS 07636.



V_o: 39 kV
Max Current: -105,600 amp
Action Integral: 1.764 x 10^6 amp^2 sec

Figure 5. Systems Tunnel LSC Lightning Strike Test—Current-Versus-Time Plot (first lightning discharge)



V_o: 58 kV
Max Current: -143,600 amp
Action Integral: 3.758 x 10^6 amp^2 sec

Figure 6. Systems Tunnel LSC Lightning Strike Test—Current-Versus-Time Plot (second lightning discharge)

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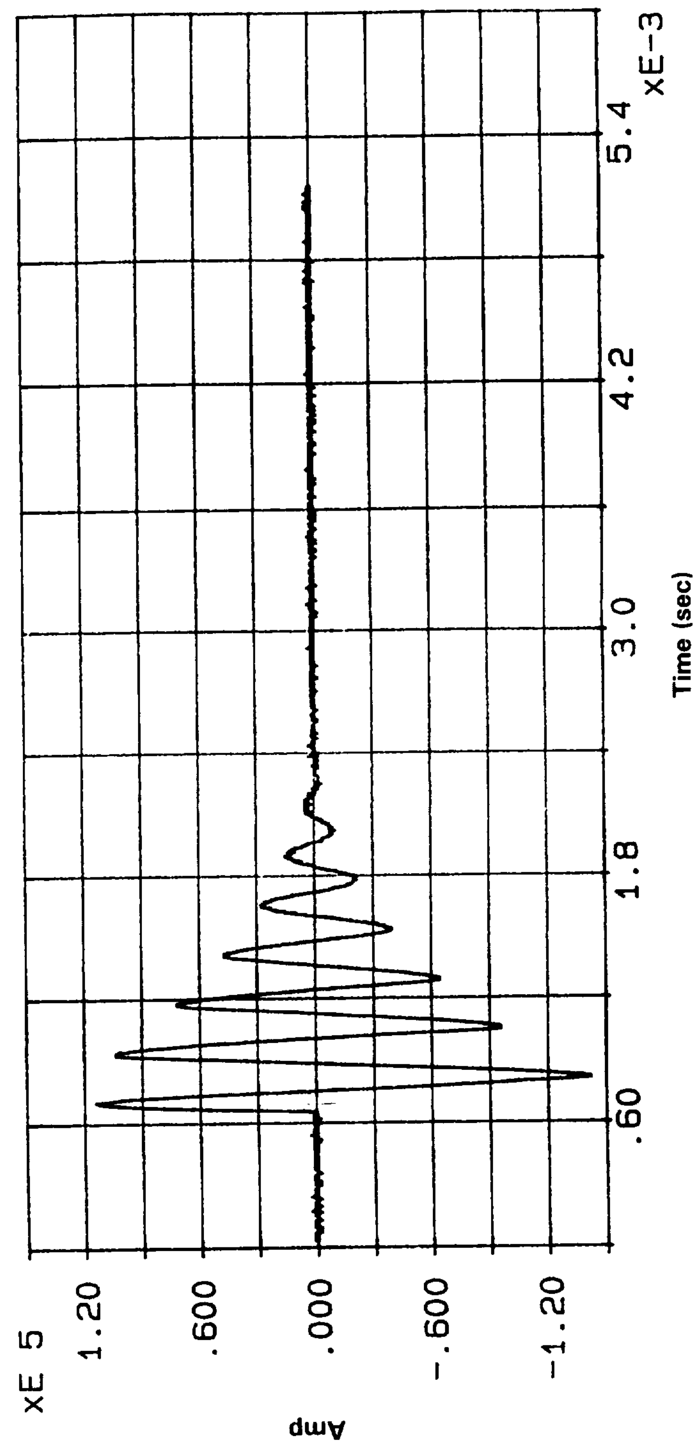

V_o: 58 kV
Max Current: -143,600 amp
Action Integral: 3.685 x 10^6 amp^2 sec

Figure 7. Systems Tunnel LSC Lightning Strike Test—Current-Versus-Time Plot (third lightning discharge)

Injected currents (143,600 amp) and action integrals (3.758 x 10^6 amp^2 sec and 3.685 x 10^6 amp^2 sec) of the second and third tests were very similar. These values were the maximum allowable for the test configuration. The injected currents were 71.8 percent of the NSTS 07636 worst-case condition of 200 kA. The action integrals were approximately 1.85 times greater than the implied maximum of 2 x 10^6 amp^2 sec in NSTS 07636.

6.3 DISASSEMBLY AND RESULTS

After the completion of lightning strike testing, the systems tunnel cover was removed for LSC visual inspection. All three grounding straps debonded and violently struck the LSC through the openings in the systems tunnel floor plates. Each grounding strap became bent into the same shape as the LSC (Figures 8 and 9). Separation of each grounding strap occurred primarily at the bondline between the strap and the adhesive. Some of the unvaporized adhesive remained on the case.

Testing in the past showed that for a systems tunnel cover lightning strike (peak current of 108,000 amp and an action integral of 2 x 10^6 amp^2 sec), only the grounding strap directly beneath the current injection location debonded, while adjacent grounding straps remained undamaged. Results of this previous testing are detailed further in TWR-19680, Cable Coupling Lightning Transient Qualification Sub-Test Flash Report. For the LSC test, it is therefore assumed that the grounding strap debonding occurred only when the straps were subjected to a lightning strike from directly above.

Slight discolorations of the LSC copper surface were detected around each grounding strap impact location. These discolorations were due to the heat produced during debonding.

After the post-test inspection, the LSC was removed and returned to the vendor for further evaluation per USBI instructions. Further inspection of the LSC by USBI personnel revealed evidence of arcing around the areas of the saddle block clamps and at each end of the LSC. This arcing indicates that current flowed on the surface of the LSC.

Final disassembly of the test article consisted of removing the three systems tunnel floor plates from the case section. It became evident that arcing occurred between the case and the systems tunnel floor plate in the vicinity of the grounding strap for the first lightning discharge (105,000 amp). This indicates that the injected current for this strike continued to flow through this area until the end of the pulse. Surfaces where the arc occurred were pitted, and small deposits of aluminum were bonded to the surface of the steel case. An analysis of the arc area was performed by personnel from the Thiokol metallographic laboratory. A Newage Portable Hardness Tester was used to measure the case hardness. Rockwell C hardness at the center of the arc (a 0.75-in.-diameter circle) ranged from 56 to 58 RC (a surface hardness in the membrane

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Figure 8. Systems Tunnel LSC Lightning Strike Test—Debonded Grounding Strap

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Figure 9. Systems Tunnel LSC Lightning Strike Test—Debonded Grounding Strap (LSC removed)

area of the steel case (regardless of depth) of 58 RC is significant enough to damage the structure of the case beyond repair). This hardness was caused by the rapid localized heating due to the arc and then rapid cooling from the rest of the case and the surrounding air. A 0.25-in. area outside of the hardened center was tempered to a hardness from 39 to 43 RC, and the unheated control surface surrounding the arc area was within the normal hardness of 42 to 46 RC. Although the case section used was previously heat damaged during the QM-8 static test fire, the area around the arc was undamaged prior to the lightning test.

A small amount of arcing occurred between the case and the systems tunnel floor plates in the vicinity of the grounding straps for the second and third lightning discharges (143,600 amp each). However, the raised portion of the case at the factory joint was located between these two strike locations, and a large amount of arcing between the case and the systems tunnel floor plates occurred in this area. It is assumed that all arcing would have taken place in the vicinity of the grounding straps (as it did for the first discharge) if flight configuration splice plates had been installed.

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APPLICABLE DOCUMENTS

Document No.	Title
10-PRC-0581	Linear Shaped Charge Assembly Procedure--Lightning Test (USBI test plan)
JSC 20007	Space Shuttle Lightning Protection Verification Document
NSTS 07636	NASA Lightning Protection Criteria Document
SYS-10-PLAN-001	SRB Systems Tunnel CO 191 Lightning Coupling Test Plan (USBI test plan)
STW4-2874	Adhesive, Electrically Conductive
STW5-3183	Ablation Compound
TWR-18364	Lightning Tests Instrumentation Report
TWR-19680	Cable Coupling Lightning Transient Qualification Sub-Test Flash Report
WTP-0195	Systems Tunnel Linear Shaped Charge Lightning Strike Test Plan
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MIL-S-8802 Type I, Class B-2	Sealant
Drawing No.	
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